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GLASS PLASTICS IN AVIATION AND ROCKET ENGINEERING

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The properties of glass plastics based on polyimide, epoxy, phenol and inorganic binders and different structures of glass fillers are investigated. Glass plastics based on epoxy binders are used to manufacture structures subject to high stresses. Glass textolites based on polyimide, silicon, and inorganic binders have been developed for use at high temperatures. Examples of the application of glass plastics in parts used in aviation and rocket engineering are presented.

Key words: glass plastics, epoxy, polyimide, organosilicon binder, mechanical properties, flammability, dielectric properties.

Glass plastics are still the most heavily used composite polymer materials in aircraft construction and elsewhere in industry, and they are simply irreplaceable in radio engineering.

Foreign and domestic specialists predict that the relative volume of polymer composite materials used will reach 45% in civilian jet aircraft (instead of 10 – 15% today) and 60% in military aircraft and helicopters. This is due to greater use of composite materials in the main structures of the wings and fuselage. Composite materials will make it possible to decrease the mass and increase the service life and fuel efficiency of aircraft.

Glass plastics are some of the first modern composites. The rapid development of glass plastics in our country began during the post-war years, when the first domestic glass fibers and reinforcing fillers based on them appeared (thread, roving braid, glass fabric, canvas, and so forth).

Using glass fillers, in 1947 – 1949 the All-Union Scientific-Research Institute of Glass Plastics and Glass Fibers developed a formula and technology for fabricating KAST glass textolite. Modified BF-type phenol formaldehyde resins, developed by G. S. Petrov, were used as binders for the first glass plastics. VIAM working together with the Scientific-Research Institute of Polymer Materials and All-Russia Scientific-Research Institute of Synthetic Fibers performed the development work on glass plastics. B. A. Kiselev and Ya. D. Avrasin, who are oldest staff members at VIAM, stood at the source of this work. Serial production of KAST-V glass textolite was organized in 1949. The development of a new type of material can be dated back to this time — construction grade composite materials.

The first glass textolite material made possible an immediate qualitative jump in improving the properties over the preceding composites based on veneer sheet (plywood, phenol impregnated modified wood) and cotton fabrics (PT and PTK textolites). The strength, water resistance, durability and other properties of the materials increased considerably. KAST textolites are still widely used in various areas of technology.

The subsequent development of aviation and rocket technology during the post-war years made it necessary to develop radioparent and heat-shielding materials which secure reliable operation of parts.

Composite materials based on different glass fillers (glass plastics, molded materials, heat-insulating mats and so forth) are still the most widely used materials in all areas of technology — 95 – 96% of all composite materials used.

This is explained by the valuable complex of strength, dielectric, heat-shielding and physical-chemical properties of glass plastics, relatively low cost, practicability, low energy consumption for processing and, which is not unimportant, an extensive raw materials and production base. In addition, in many cases glass plastics decrease not only the mass of structures but also labor intensiveness as well as materials and production costs, which gives a considerable economic savings.

Like other composite materials, glass plastics are multiphase heterogeneous systems whose properties depend on the properties of the initial components and how these components interact with one another. The advances made in the development of composite materials are largely the result of

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TABLE 1. Properties of Epoxy Binder Based Glass Plastics

Properties	Glass plastic			
	VPS-5	ST-69N	VPS-30k	ST-2227
Strength, MPa:				
tensile	560	630	1050	560
compression	440	550	570	550
bending	570	900	1070	970
Elastic modulus in tension, GPa	27	29	51	28
Dielectric constant ε at 10^6 Hz	5.44	4.58	4.38	4.88
Tangent of the angle of dielectric losses $\tan\delta$ at 10^6 Hz	0.012	0.016	0.034	0.014

fundamental research on the development of reinforcing fillers, synthesis of polymer binders and study of interphase boundaries.

A wide range of fillers based on glass fibers with different chemical composition — thread, cords, canvas, fabric, knitted fabric and three-dimensionally reinforced multilayer and machine-sewn fabrics — was used in the development of glass plastics.

The diversity of the forms of glass fillers and the variation of their characteristics due to the variation of the chemical composition has predetermined the possibility of creating glass plastics with a very wide range of properties [1]. For example, fillers comprised of glass containing lead oxides have made it possible to develop radiation-resistant protective structures, while glass fillers with magnesium-aluminum-silicate composition (with strength 5000 MPa) have made it possible to develop materials for parts subjected to large loads, such as aircraft and helicopter blades, tanks with working pressure 400 atm and higher.

The spars of the helicopter blades developed using cord glass fabrics have increased fatigue strength and reduced the mass of helicopter blades and helicopters as a whole, which, in turn, reduced fuel consumption and increased the payload and service life of this technology. The advantage of such blades was especially clearly manifested in the development of high-speed machines, where the capability of composite materials to withstand large, variable loads was most fully realized, as well as in the development military helicopters, whose blades must remain serviceable even after serious damage has been sustained. The service life of blades made of composite materials is two to three times longer than that of metal blades; a 5 – 10-fold increase is possible in the future. High-strength glass plastics have made it possible to develop the longest in the world (1800 mm) blades for profan engines of prospective aircraft — AN-70, AN-140, IL-114, and others.

The development of glass plastic for parts used in aviation and rocket technology, which operate under extreme conditions, required solving a number of coupled scientific-engineering problems, including, together with the study and selection of glass-fiber fillers, the synthesis of binders as well as the study of the binder-filler interaction. The scientifically substantiated, directed synthesis of binders for glass plastics is possible provided that the principles determining the fullest realization of the physical-chemical properties of glass plastics are known — the relation between the composition, polymer structure, properties of the polymer and chemical composition of the glass filler and character of its surface treatment [2].

In regards to synthesis of binders for glass plastics to be used for different purposes, the problem reduced to eliminating the drawbacks inhering in individual polymer binders by modifying them as well as to attaining the optimal combination of physical-mechanical and technological properties of the glass plastics based on them. For the development of glass plastics, a formula for the binder was investigated and the principal directions of the solidification reaction were studied for both pure binders and prepregs based on them, and the main technological parameters for processing glass plastics were determined.

Unsaturated polyesters, phenol formaldehyde, epoxy, and organosilicon resins have found the greatest applications in the production of glass plastics. Because of the existence of a raw materials base with quite good technological and physical properties these polymer materials served as a foundation for developing construction, radio-engineering, and heat-shielding glass plastics.

The properties of some glass plastics based on epoxy binders are given in Table 1.

A theoretical analysis of the structure of glass plastics shows that the strength of the binder and filler is determined by the adhesion of the binder to the filler, shrinkage of the polymer binder in the process of solidification and ratio of the linear thermal expansion coefficients of the glass fiber and the binder in a wide working temperature range.

The operating simultaneity of glass-plastic components also depends on the cohesive strength of the binder and its deformation properties. It is obvious that the maximum bonding strength between a glass fiber and the binder obtains only with good permeation of the binder into the glass.

TABLE 2. Properties of Glass Plastics Based on Organosilicon Binders

Properties	Glass plastic			
	SK-9FA	SK-9KhK	SK-101	SK-9-70K
Strength, MPa:				
tensile	380	270	140	350
compression	115	100	80	140
bending	200	200	135	275
Elastic modulus tension, GPa	26	24.7	14.6	27
Dielectric constant ε at 10^6 Hz	4.66	3.53	3.70	3.13
Tangent of the angle of dielectric losses tan δ at 10^6 Hz	0.0026	0.0047	0.015	0.0046

The development of high-strength glass plastics which maintain satisfactory strength at medium and high temperatures made it possible to expand their range of application and to increase part quality and reliability.

Glass plastics also developed in different, very important directions. An entire series of thermally stable glass plastics based on organosilicon, polyimide and inorganic binders was developed. These materials, which can function for a long time at 300 – 350°C and for a short time to 800°C, found wide application in aviation, rocket-space and other areas of technology.

In the course of the development of heat-shielding and radioparent materials for aviation and rocket-space engineering, operating at high temperatures with large velocity differentials, materials were created on the basis of whole-fabric single- and multilayer blanks and jackets made of thermally stable silica and quartz fibers. These materials made it possible to develop completely new and novel structures for the cone parts of intercontinental ballistic missiles. Glass plastics based on multilayer fabrics have also found wide applications for the external and internal heat-shielding of engines and bodies.

Organosilicon and polyimide polymers containing elemental organic fragments, linear or reticular carbo- and heterocyclic aromatic systems are the foundation of thermally stable matrices.

Organosilicon binders are of interest because of their high thermo-oxidative stability and good electric properties.

A number of organosilicon polymers have low shrinkage and good adhesion to glass fiber. Only some organosilicon resins show small shrinkage; small shrinkage is due to the fact that the resin solidification process largely proceeds by opening of rings and good adhesion is explained by the presence of hydroxyl and ethoxy groups in the polymer, as a result of which strong van-der-Waals forces and hydrogen and chemical bonds can arise, as well as by the uniformity of the main structure of the organosilicon polymer and glass. The large dimensional change and low strength of organosilicon polymer is due to its high polydisperseness, low linkage frequency and weak inter- and intramolecular interaction forces. Investigations have confirmed that modification of polymers at the intermolecular level can alter their properties over a wide range, affecting in this way the initial properties of the binders. For example, modification of the resins indicated by surfactants, which lower the surface tension, greatly improves wetting. Modification by high-molecular compounds containing hydroxyl and ethoxy groups strongly affects adhesion, thermally induced dimensional change, and mechanical properties of the polymers.

The comparatively low strength and high processing temperature (250°C and higher) of glass plastics based on this class of binders are among the drawbacks characteristic of this class of binders.

The use of special hardeners made it possible to create the organosilicon binder K-9Kh, based on which glass plastics can be made at 150°C. Research is being conducted on composite materials such as ceramoplastics with working temperatures above 1000°C. Samples of such materials were obtained with high-temperature treatment of plastics based on polyorganosiloxanes in the absence of oxygen. Using an oligomer of organosilicon resin K-9-0 as the active solvent, the organosilicon binder K-9-70 was developed, making it possible to prepare articles by permeation under pressure. The main properties of organosilicon glass plastics are presented in Table 2.

Polyimide binders have become especially important in the production of high-temperature glass plastics [3]. They are incombustible, possess high thermal stability and are radiation, fungal, and corrosion resistant, and their physical-chemical characteristics remain at a quite high level at elevated temperatures.

The polyimide binders SP-97s and SP-TsM have found the greatest application in the manufacture of glass plastics. The drawbacks of these binders are high processing temperature (300 – 350°C) and high porosity of glass plastics based on them.

Research has been done on the modification of polyimide binders to improve the technological properties and decrease the porosity of polyimide glass plastics without greatly lowering the mechanical strength and heat and fire

TABLE 3. Properties of Glass Plastic Based on Polyimide Binders

Properties	Glass plastic			
	STP-97s	STP-97K	STP-1TsM	STM-F
Strength, MPa:				
tensile	500	490	650	475
compression	350	400	–	640
bending	640	400	900	700
Elastic modulus under tension, GPa	34.2	30	–	33
Dielectric constant ε at 10^6 Hz	4.71	4.57	4.1	4.54
Tangent of the angle of dielectric losses tan δ at 10^6 Hz	0.012	0.0081	0.01	0.006

resistance. One glass plastic developed was STP-07K whose processing temperature is 170°C with no loss of mechanical strength or fire resistance.

The introduction of carborane groups into the structure of polyimide increases heat-tolerance of glass plastics based on polyimide binders. Glass plastics with reduced porosity (STM-F) and higher mechanical properties have been obtained on the basis of PAIS-104 and PIK-250 oligoimides with working temperature 250°C [4]. The properties of glass plastics based on polyimide binders are presented in Table 3.

Glass plastics based on organic and elemental organic matrices can function for a long time only at temperatures to 400°C. However, in different areas of technology there is a need for materials which are more heat-tolerant. Matrices based on inorganic binders (aluminum phosphate and aluminum chromophosphate) are used to develop such glass plastics. The aluminum phosphate binder SAFS was used to develop a series of glass plastics STAF-1, -2, and -0 on the basis of the glass fabrics KT-11-TO-OP1 with a special coating and AFK kv, where quartz glass fabric was used as a filler. By their nature and stability at high temperatures STAF-type glass textolites correspond more to a ceramic material. At the same time they are fabricated by the standard technology adopted for fabricating composite materials without sintering at high temperatures. Unlike brittle ceramics, inorganic glass textolite can be subjected to all forms of mechanical processing by diamond and hard-alloyed tools. These materials possess comparatively low mechanical strength, but they withstand temperatures to 1100°C. They can be used to manufacture articles with a complicated configuration.

The properties of glass plastics based on aluminum phosphate binder are presented in Table 4.

The areas of application of heat-resistant glass plastics in different areas of technology are now known. These materials are mainly used to manufacture the radomes of radar stations for use with high-velocity rockets; polyimide glass plastics are use to manufacture a long list of parts used in the internet and different heat-insulating structures.

Other polymer materials or metals can be used in some parts, but glass plastics are simply irreplaceable in radio engineering structures. The military qualities of aviation technology and the reliability and safety of transporting passengers are largely determined by the quality and reliability of the radio engineering materials which are used in the manufacture of radioparent radomes. Aside from protection for antennas from external actions, the materials must secure minimal losses and distortions of electromagnetic waves passing through the radome wall.

A series of radioparent materials which have found wide application in radomes with honeycomb, grid, and monolithic construction has been developed on the basis of different binders and fillers. Capillary (hollow) quartz fibers and microspheres used as glass plastics have made it possible to obtain materials with unique dielectric properties. The adop-

TABLE 4. Properties of Glass Plastic Based on Inorganic Binders

Properties	STAF-2		AFK kv	
	20°C	800°C	20°C	1100°C
Strength, MPa:				
tensile	30	55	60	50
compression	75	80	75	60
bending	80	100	85	50
Dielectric constant ε at 10^6 Hz	3.4	3.43	3.53	3.58
Tangent of the angle of dielectric losses tan δ at 10^6 Hz	0.015	0.023	0.008	0.02

TABLE 5. Properties of Microsphere Glass Textolites with Different Binders

Binder type	Properties of Microsphere Glass Textolites				
	Density, g/cm^3	Rupture stress under static bending, MPa	Dielectric constant ε at 10^{10} Hz	Tangent of the angle of dielectric losses tan δ at 10^{10} Hz	Working temperature, °C
Diallyl isophthalate	0.75 – 0.8	137	2.33	0.009	200
Epoxy	0.85 – 0.9	259	2.44	0.014	150
Epoxy, inflammable	0.65 – 0.7	163	2.21	0.016	80
Phenol	0.65 – 0.7	120	2.53	0.017	170
Organosilicon	0.75 – 0.8	126	2.10	0.005	300
Polyimide	0.8 – 0.85	247	2.39	0.012	400

tion of radioparent glass plastics based on these fillers has made it possible to reduce the mass of the dome structures by 15 – 20% and increase their tactical-technical performance characteristics.

Development work on new materials for construction and radio-engineering applications, where hollow microspheres are used in addition to conventional wave fillers, has been performed in recent years. So-called syntactic composite materials have half the density, dielectric permeability, and thermal conductivity compared with glass plastics. Microspheres make it possible to obtain materials with prescribed low density and dielectric permittivity, while the closed cellular structure of sphero-plastics guarantees stable properties and high operational reliability, especially for operation under poor atmospheric conditions.

Micro-sphero-glass textolites based on various binders and glass microspheres have a small dielectric constant ε and tangent of the angle of dielectric losses tan δ. Synpregs based on different binders are distinguished by a long service life (6 months at 20°C) and elasticity, which makes it possible to manufacture from them complex blanks and to process the blanks into parts by the same methods used for glass plastics.

Micro-sphero-glass textolites based on epoxy binders have found application in a number of aviation structures — large cowlings, panels, barriers and others. They have a number of technological advantages in the manufacture of single- and multilayer structures. The main advantage is that they can be molded in a single operation at low pressures in rigid molds or by vacuum and autoclave molding methods. This gives a thin wall. The low-mass parts obtained possess high strength and rigidity, operate reliably, and assure high electrotechnical performance. Such materials have been used to manufacture large-size radioparent structures of ground- and sea-based aircraft, where mass reduction, improved characteristics, and improved operational reliability are guaranteed, for example, the nose antenna cowling of the Be-200.

Micro-sphero-glass textolites based on organosilicon and polyimide binders have been developed for objects operating at elevated temperatures. Compared with honeycomb structures, the radio-engineering properties of parts have increased and the costs of fabricating a large number of fixtures and finishing every cover have decreased.

The properties of these materials are presented in Table 5. Different glass fabrics and glass or silica microspheres are used as reinforcing fillers.

The large contribution made by the manufacture of large-size glass-plastic articles to the development of new technological processes should be noted. One example is the manufacture of construction, radiotechnical, and heat-shielding parts by means of permeation under pressure. The adoption of this method at serial production plants made it possible to fabricate very high quality articles with stable physical-mechanical and radio-engineering characteristics as well as to completely eliminate contact between workers and toxic binders.

Together with the manufacture of nose parts and antenna cowlings by permeation under pressure based on polymerization binders (epoxy, polyester) the first in the world technology for manufacturing large-size (to 2 m) parts using high-temperature polycondensation binders (phenol, organosilicon, polyimide) was developed and adopted.

A great deal of work was performed on the development of fireproof glass plastics and trilayer structures for finishing the interiors of the cabins in passenger jets, meeting modern requirements. This problem was posed in connection with the development in Russia of wide-body passenger jets capable of carrying 350 or more passengers. After long-time tests a light-weight polyimide interior was chosen for the first Russian aerobus IL-86, meeting all strength and passenger-safety requirements.

New materials with improved characteristics with respect to all indicators (strength, flammability, manufacturability and external appearance) have been developed in the last few years. This has made it possible to recommend them not only for jet interiors but also for finishing cabins in different means of transportation as well as in construction.

Although extensive work on the development and application of composite materials based on other fillers (carbon, organic) has been performed in recent years, because of their low cost and extensive raw-materials and production base

glass plastics will hold the lead among composite materials with respect to the volume of usage in industry.

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